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Full Scale Measurements of Wave Impact on a Flat Plate

By

Anne M. Fullerton, David Drazen, Don Walker and Eric Terrill

NSWCCD-80-TR–2012/005 FULL-SCALE MEASUREMENTS OF WAVE IMPACT LOADING ON A FLAT PLATE

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14. ABSTRACT

Full scale measurements of wave impact loads and their statistics in real sea states are desirable for validation of numerical simulations and for application to marine engineering design problems. Measuring and/or estimating wave forces on flat plates are especially problematic due to statistics of large waves in a given sea state, the intermittent statistics of wave breaking, the sensitivity of the loading relative to the phase of the incoming wave and scaling issues when translating from model scale data to full-scale. To increase our understanding of wave hydrodynamic pressures on a flat plate, an instrumented plate was deployed from the Scripps Institution of Oceanography's research pier. The instrumented plate is exposed to a wide range of wave conditions with a significant wave height (Hs) ranging from 3-4 m in the winter and Hs in the 1-2 m range in the summer. The instrumented flat plate is composed of three discrete modules each containing 6 pressure gages. Data are being collected over an extended period, nominally 12 months, to characterize extreme value

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14. ABSTRACT (continued)
due to wave impact loading. Preliminary analysis of the data is presented and discussed.

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INTERNATIONAL SYSTEM OF UNITS (SI) CONVERSION LIST

U.S. CUSTOMARY	METRIC EQUIVALENT
1 inch (in)	25.4 millimeter (mm), 0.0254 meter (m)
1 foot (ft)	0.3048 meter (m)
1 pound-mass (lbm)	0.4536 kilograms (kg)
1 pound-force (lbf)	4.448 Newtons (N)
1 foot-pound-force (ft-lbf)	1.3558 Newton-meters (N-m)
1 foot per second (ft/s)	0.3048 meter per second (m/s)
1 knot (kt)	1.6878 feet per second (ft/s) 0.5144 meter per second (m/s)
1 horsepower (hp)	0.7457 kilowatts (kW)
1 long ton (LT)	1.016 tonnes 1.016 metric tons 1016 kilograms (kg) 2240 pounds
1 inch water (60F)	248.8 Pascals (Pa)

ABSTRACT

Full scale measurements of wave impact loads and their statistics in real sea states are desirable for validation of numerical simulations and for application to marine engineering design problems. Measuring and/or estimating wave forces on flat plates are especially problematic due to statistics of large waves in a given sea state, the intermittent statistics of wave breaking, the sensitivity of the loading relative to the phase of the incoming wave and scaling issues when translating from model scale data to full-scale. To increase our understanding of wave hydrodynamic pressures on a flat plate, an instrumented plate was deployed from the Scripps Institution of Oceanography's research pier. The instrumented plate is exposed to a wide range of wave conditions with significant wave height (Hs) ranging from 3-4 m in the winter and with Hs in the 1-2 m range in the summer. The instrumented flat plate is composed of three discrete modules each containing 6 pressure gages. Data are being collected over an extended period, nominally 12 months, to characterize extreme value distributions due to wave impact loading. Preliminary analysis of the data is presented and discussed.

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ADMINISTRATIVE INFORMATION

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INTRODUCTION

Full scale measurements of wave impact loads and their statistics in real sea states are desirable for both testing computational fluid dynamic codes (CFD) [1, 2] and for application to marine engineering design problems [3]. High-precision and repeatable measurements of wave impact loading are possible in the laboratory, [4, 5], but difficult in the field. Extreme value statistics have been used in ocean engineering applications to identify 100-year wave heights based on wave hindcasts [6] and have been used to estimate wind speeds [7], surface currents [8], and sea level [9]. Estimating the largest expected full-scale wave forces on a flat plate over long return periods are especially problematic due to statistics of large waves in a given sea state, the intermittent statistics of wave breaking, the sensitivity of the loading relative to the phase of the incoming wave and scaling issues when translating model scale data to full-scale.

To increase our understanding of wave hydrodynamic forces on a flat plate, a full scale instrumented plate was fabricated, deployed, and is being operated presently from the Scripps Institution of Oceanography research pier for purposes of gathering data across a wide range of wave conditions. This paper will describe the set-up of an outdoor "laboratory," operational since December 2011. Data is still being collected so only an initial dataset will be used in this report. A description of the research pier at Scripps Institution of Oceanography will be given along with an overview of the wave climatology. Discussion of the work performed in FY12 will be detailed.

EXPERIMENTAL SETUP

Scripps Pier

The Scripps research pier (Figure 1), located in La Jolla, California, is owned and maintained by the Scripps Institution of Oceanography, University of California San Diego. The pier sits upon an array of 0.67 m diameter steel reinforced concrete pilings, supports a concrete deck 10.25 m above Mean Lower Low Water (MLLW) and is 330.5 m long. Water depth at the end of the pier is approximately 8 m above MLLW. The bathymetry near the pier deepens rapidly and contains two prominent canyons, as shown in Figure 2. Since the waves do not propagate over a broad shelf; large waves and swell are common during winter storms. Tides in the San Diego region are semidiurnal and have a maximum excursion of approximately 2 m during spring tides.

The facility is restricted from public access, and has a number of features suitable for conducting long term research activities, including support of environmental sensors, a 2 ton hoist for launching small boats and a number of portable laboratories for housing research equipment. Wave height time series are continuously collected by the Coastal Data Information Program (CDIP) using a pressure sensor mounted on the second piling from the north, on the west end of the pier, 15.13 m below the top surface of the pier deck. The Paroscientific Digiquartz sensor (series 2000 model) has an absolute accuracy of 0.01%, repeatability of 0.005%, and is sampled at 1 Hz. The long term operation (1976-present) of the gage has allowed for the wave climatology at the pier location to be well characterized. In addition to the local wave measurements, meteorological data (winds, relative humidity, air/sea temperatures, and barometric pressure) is collected at the end of the pier using sensors that meet or exceed World Meteorological Organization (WMO) standards.

Figure 1. Photograph of the research pier located at Scripps Institution of Oceanography.

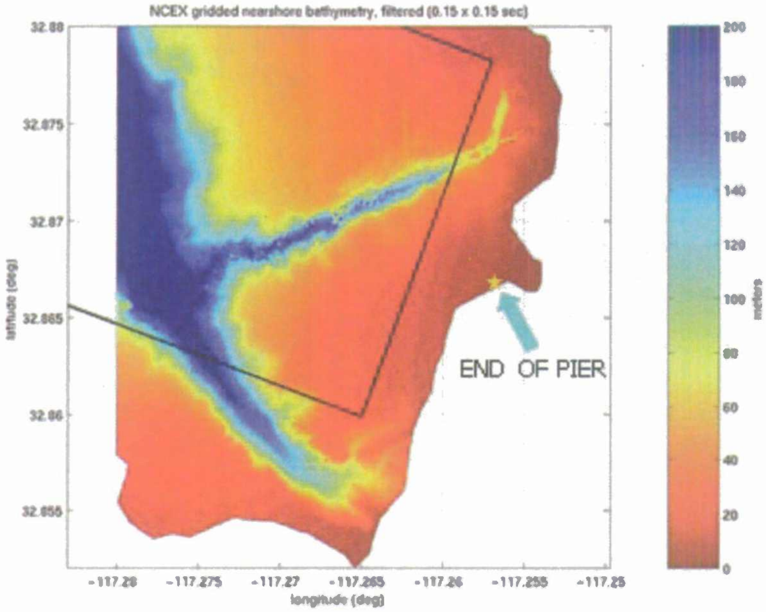

Figure 2. Ocean bathymetry in the region of the pier.

Wave Climatology at Scripps Pier

Wave climate in Southern California is best characterized by Munk, et. al. [10], and Arthur et. al. [11] and has been shown to be composed of six major wave types that deliver energy to the shoreline [12]. The sources of wave energy include: 1. Aleutian Low, 2. Pineapple Express, 3. Northwest Swell, 4. Tropical Storm, 5. Southern Hemisphere Swell, and 6. Local Sea Breeze. The sources are both seasonal in nature and have inter-annual variability depending on the phase of Pacific Ocean El-Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) cycles. These climate cycles influence the location and intensity of storms in the Pacific basin with sources 1-3 arriving from the west and northwest and sources 4-5 arriving from the south. Local sea breeze is due west and generally much higher frequency in nature. The variation in sources introduces a wide range of wave conditions at the Scripps Pier due to its western exposure (Figure 3), with North Pacific generated waves ranging from 3-4 m, while summer conditions occasionally have low frequency south swell in the 1-2 m range. Example annual statistics for 2006 are presented in Figure 4 to illustrate the range of conditions typically found over a 12 month period. Return levels of the monthly maximum measured significant wave height measured at the end of the Scripps Pier between 1976 and 2007 are provided in Figure 5 to illustrate the type of maximum waves the plate may be exposed to over the course of its operation. In general, a monthly maximum wave height in exceedance of 3 m is expected approximately 4% of the time.

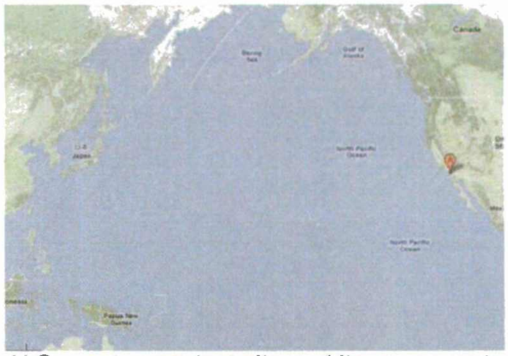

Figure 3. Location of the U.S. west coast test site and its exposure to both north swell from the Gulf of Alaska and the south swell from the southern ocean.

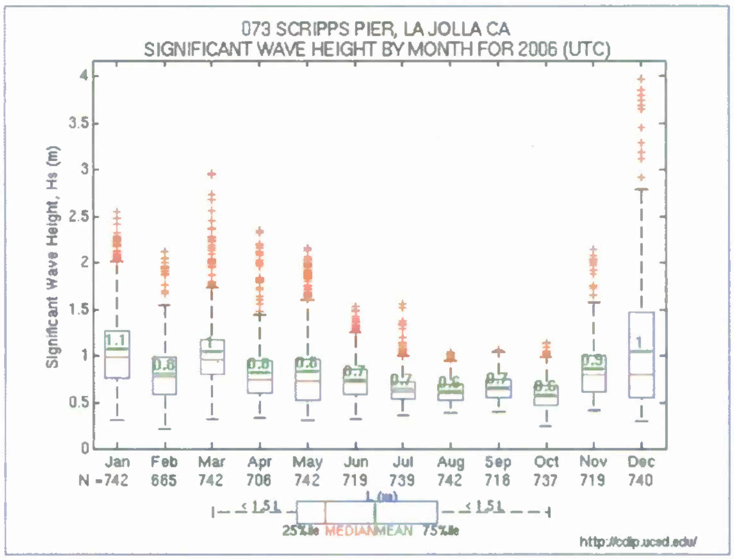

Figure 4. Scripps Pier significant wave height statistics for 2006. Presented are the mean, median, and lower and upper quartiles. (Data available from http://cdip.ucsd.edu)

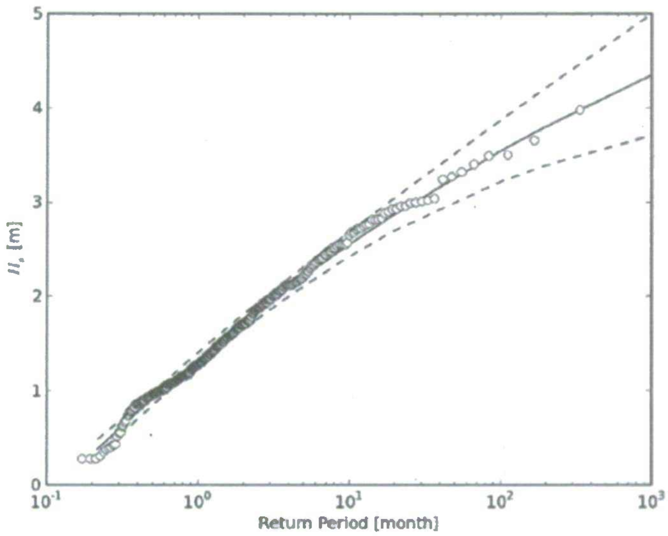

Figure 5. Monthly return levels for maximum wave height at SIO pier. Data used are monthly maxima between 1967-2012. These waves are likely depth-limited and breaking or near-breaking at the time of measurement. Hs is significant wave height and dashed lines are 95% confidence limits on extrapolated values.

Flat Plate Design and Installation

To gather long term measurements for statistical characterization of wave impact loads, an instrumented flat plate was designed for an extended deployment from the most seaward pier piling, as shown in Figure 6. With dimensions of 0.61 m x 1.83 m, the plate was attached to a mounting bracket fabricated from hot dipped galvanized tubing. The plate was offset from the piling by two piling diameters (1.34 m) to minimize flow distortion of the incoming wave. The brackets were designed with adequate cross-bracing to stiffen the structure and minimize any load absorption. Because the bracket clamp is circular, and the piling has flat sides, pressure treated wood blocks were used in between the clamp and piling. The plate is oriented vertically and positioned so that mean sea level (MSL = MLLW + 0.832 m) is at the lower third of the plate. This orientation was chosen so that the plate would not be fully submerged during large wave events, allowing impact loads to be measured. Photographs of the installed plate are shown in Figure 7, Figure 8, and Figure 9. Three square faced instrumented modules (0.39 m x 0.39 m) designed to measure point pressure loads and integrated impact loads are installed onto the plate. A modular design was chosen to allow for servicing of the sensors without removal of the entire mounting structure. The face of the module sits flush with the surrounding plate material. The modules are a two piece design, sealed with an o-ring and fabricated from an ultraviolet resistant Acetal co-polymer to eliminate corrosion issues that may arise from the long duration deployment. Each module has an array of 6 pressure gages (Keller model PA-10LH/5BARD/8963.3, 0-500 kPa range) as well as a slam panel (0.29 m x 0.29 m x 3.175 mm thick) that is instrumented with strain gages, as shown in Figure 10. Preconditioning analog circuitry for the pressure sensors and strain gages are contained within each panel close to the sensors to reduce noise. Each module has a multi-pin underwater connector on the back and waterproof cables for each of the three modules connect the modules to a data acquisition system located in a laboratory building immediately above the panel.

Time-synchronized measurements of the free surface just forward of the plate are captured to measure the waves prior to impact with the plate. The measurements are made with a 905 nm laser range finder (model ILM-1500, MDL Corporation) that operates at a pulse repetition rate of 1 kHz and conditionally averaged to 20 Hz. Supporting these measurements are an array of above-water video cameras that can record time-synchronized video of the waves as they approach the plate. All signals are sampled in real-time using a National Instruments Data Acquisition Card and recorded using LabView Software. The software is written so that the panel can continuously sample round the clock. If needed, the signals can be viewed remotely using high speed Ethernet connections, with the ability to transfer data from the hard drives for post analysis. All signals are sampled continuously at 20 kHz into a buffer. Local maxima above 10.34 kPa are stored from the buffer at the full 20 kHz resolution for 0.75 s before and after the event to capture the high bandwidth, transient loads that occur on impact. The remaining channels are decimated to 1 kHz and stored to have a continuous record during testing.

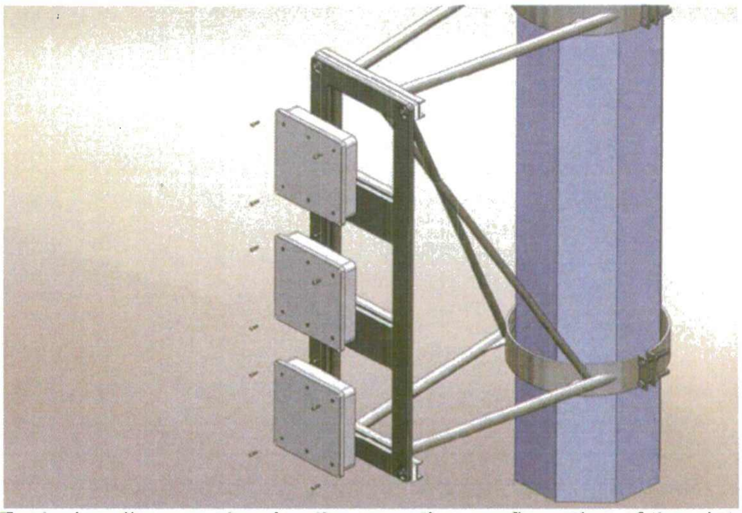

Figure 6. Explosion diagram showing the mounting configuration of the plate and three instrumented modules designed to measure wave impact loads. The deployed system has the modules rotated 90 degrees from this diagram, see Figure 8.

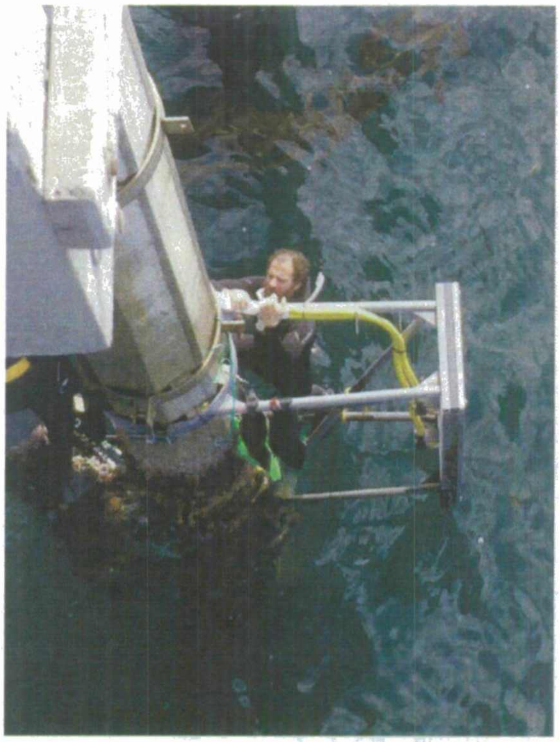

Figure 7. Installation of the plate by divers after being lifted into place by crane.

Figure 8. Plate view as seen by incoming waves.

Figure 9. A wave impact event on the instrumented plate. The plate's distance off the pier piling minimizes any flow distortion or wave reflections from the pier piling that the plate is mounted to.

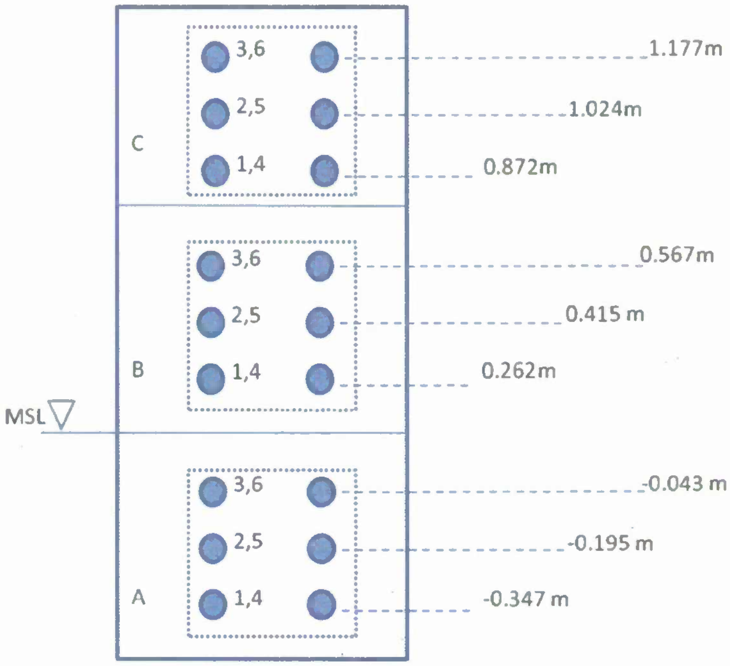

Figure 10. Sketch of pressure gage and slam panel layout with heights referencing mean sea level (MSL). Blue circles represent pressure gages and dashed lines represent the slam panels. The modules are referred to as A, B, and C, where A is the lowest module.

DATA ANALYSIS

Long Term Trends

As described above, all signals are sampled continuously at 20 kHz into a buffer. When a pressure above 10.34 kPa is measured, the full 20 kHz resolution for 0.75 s before and after the event is recorded. At all other times, the data are decimated to 1 kHz and stored as a continuous record during testing. To investigate long term trends, the non-continuous 2 second (s) records from pressure gage A2 were averaged and compared with the laser altimeter data to determine if the gages were working properly. Since the A bank of pressure gages were the lowest, they should capture much of the tidal range. Figure 11 shows this record for a period of approximately 24 hours on 7 January 2012. Figure 12 shows the same for a longer time period beginning 20 April 2012. The slower tidal signal can be seen in both records, though the pressure gages does not measure low tide because the water is below gage level at that point. These plots suggest that the pressure gages are properly measuring water level.

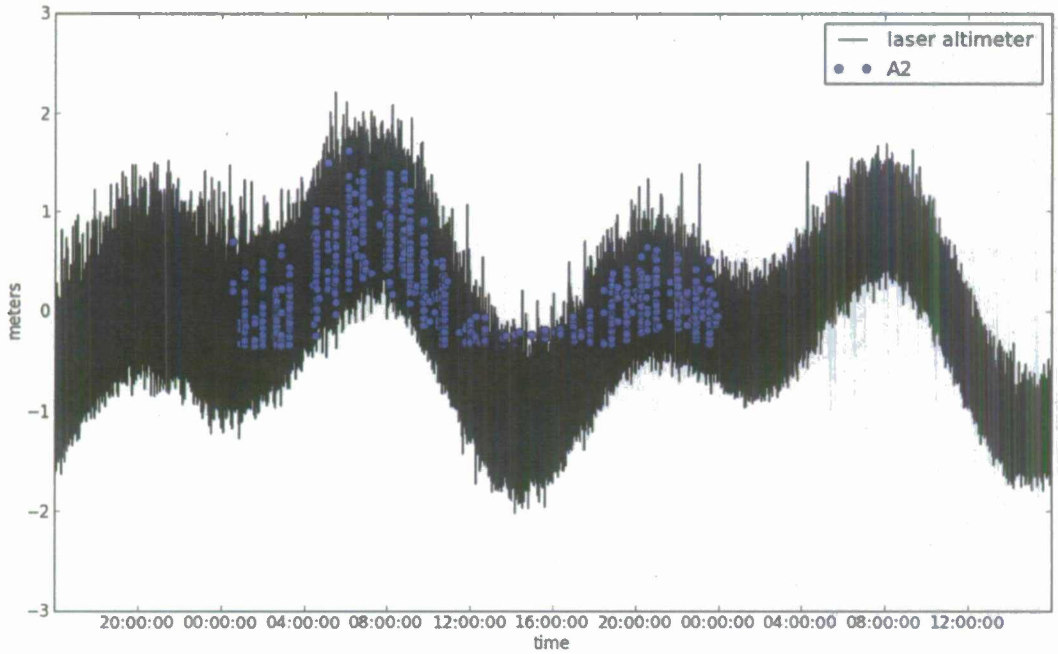

Figure 11. Comparison of averaged 2s pressure gage measurements (A2) with laser altimeter measurements from 7 January 2012.

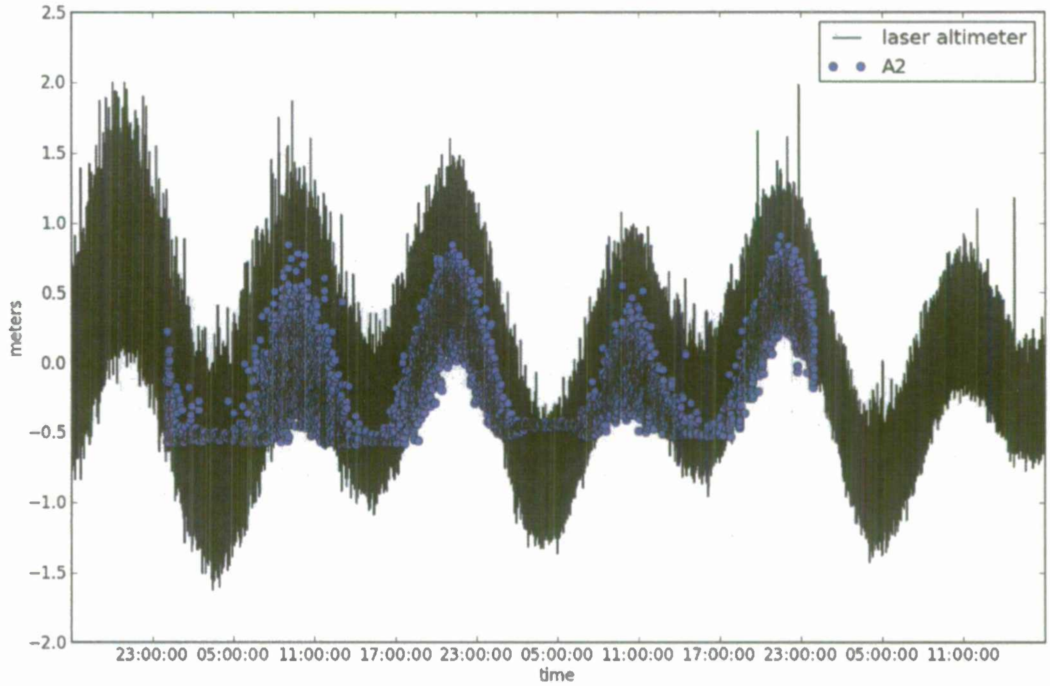

Figure 12. Comparison of averaged 2s pressure gage measurements (A2) with laser altimeter measurements for 20-21 April 2012.

Slam Analysis

To determine the peak pressure values on impact, the following method was implemented on the 2 s pressure records:

1. Downsample 20 kHz data to 2 kHz.
2. Detrend 2 kHz data.
3. Demean 2 kHz data.
4. Find up and down crossings at the 3.44 kPa (0.5 psi) level.
5. Find peak between up and down crossings.
6. Retain highest peak as slam (noting that some series may have no slams because of changes in the pressure signal due to water level or potential drift).

Figure 13 and Figure 14 show examples of this analysis for two different 2 s pressure records where impacts are detected and designated by a star. Figure 15 shows an example of a file with no visible impact. Using this method will detect false peaks in records where there is a sudden change in the pressure reading that may be due to electronic noise or drift, as shown in Figure 16. To eliminate these peaks, any records where the ending pressure is more than 10 kPa greater than the beginning pressure are not included in the analysis. Since peaks tend to be on the order of 10 kPa, this would indicate a pressure record that peaked and did not recover in that run.

To investigate the data further, the pressure series from Figure 13 and Figure 14 were plotted along with the time series from the laser altimeter, and are shown in Figure 17 and Figure 18. It appears that waves of approximately 1.5 m occur just before the larger peaks are recorded for both time series. The method of finding peaks was applied to all records for pressure gage B1 on 7 January 2012. Figure 19 shows the resultant PDF of these slams, which are centered around approximately 10 kPa. Figure 20 shows a PDF of the wave heights measured concurrently. Only waves with periods greater than 1s are included in the PDF.

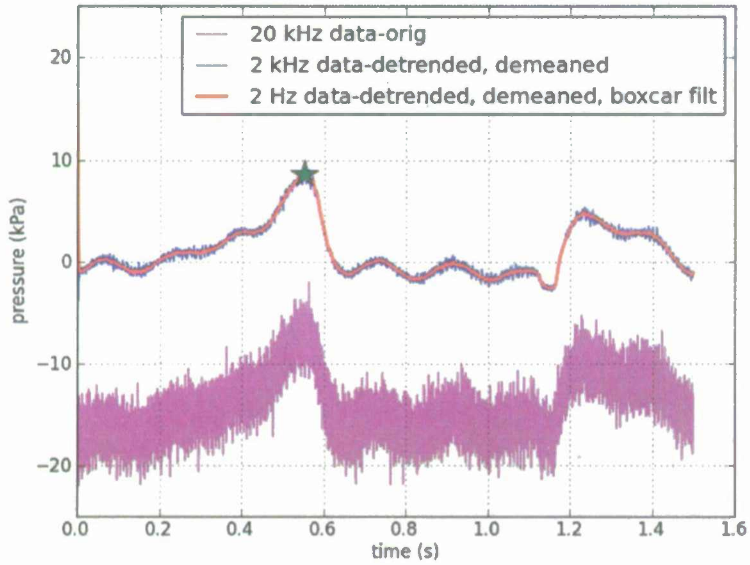

Figure 13. 2 second long pressure time series from 7 January 2012 at 04:50 showing a wave impact designated by a star.

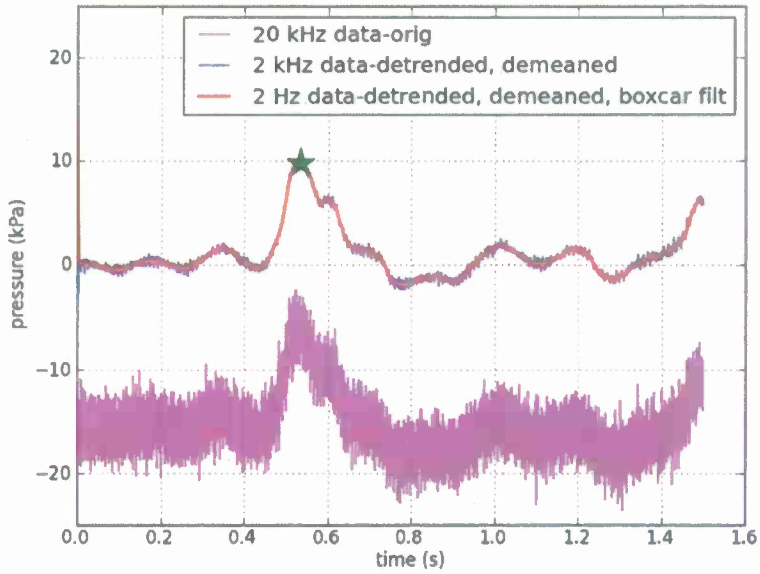

Figure 14. 2 second long pressure time series from 7 January 2012 at 04:54 showing a wave impact designated by a star.

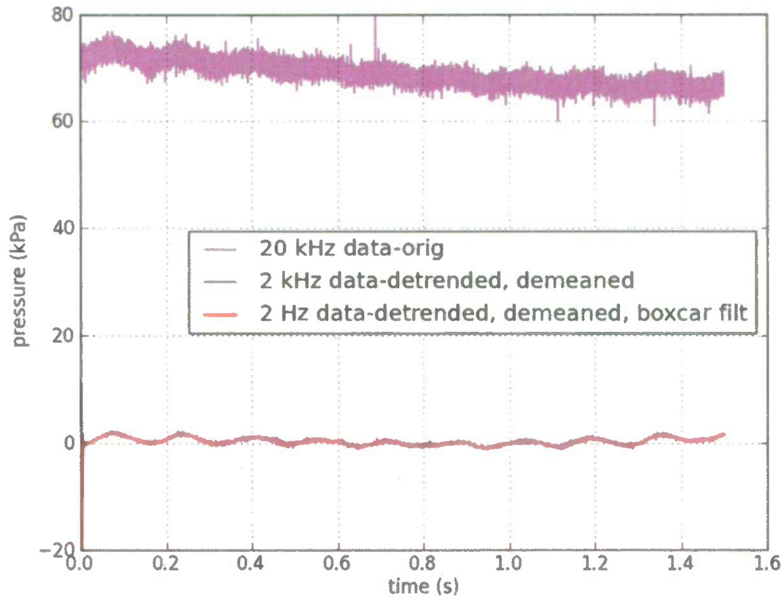

Figure 15. 2 second long pressure time series from 7 January 2012, with no visible impact measured.

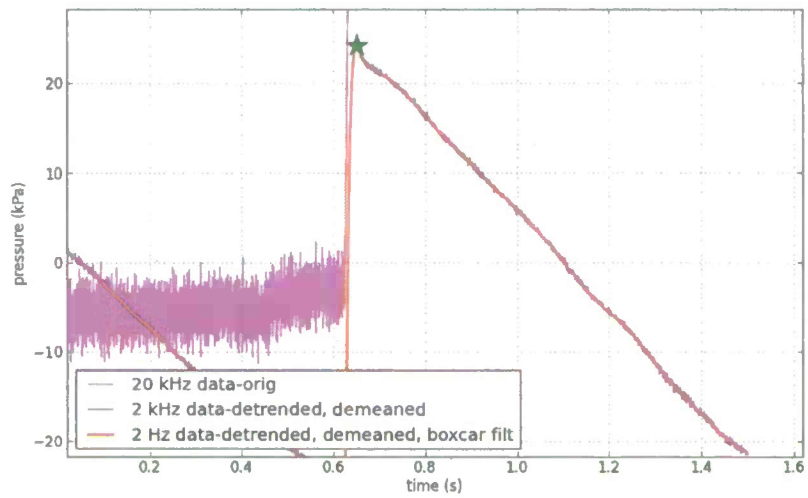

Figure 16. 2 second long pressure time series from 7 January 2012, with “false” impact detected.

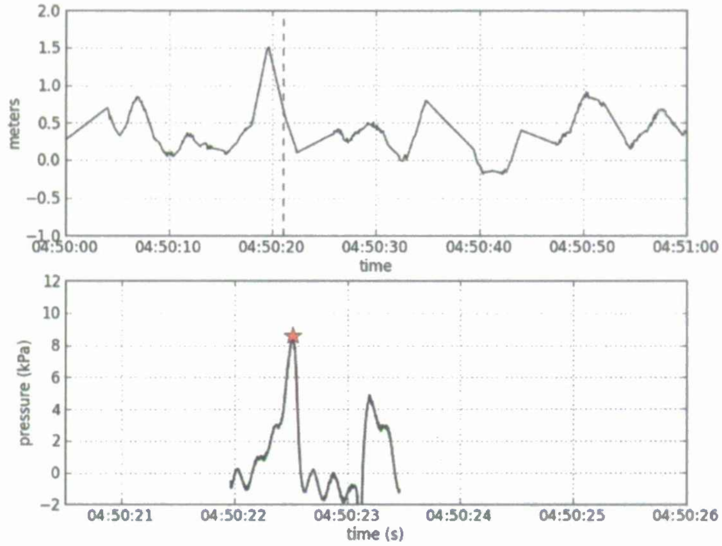

Figure 17. Laser altimeter (top) and pressure gage B1 (bottom) time series for 7 January 2012 (same series as Figure 13). Dashed line in top panel indicates location of impact indicated by red star in the bottom panel.

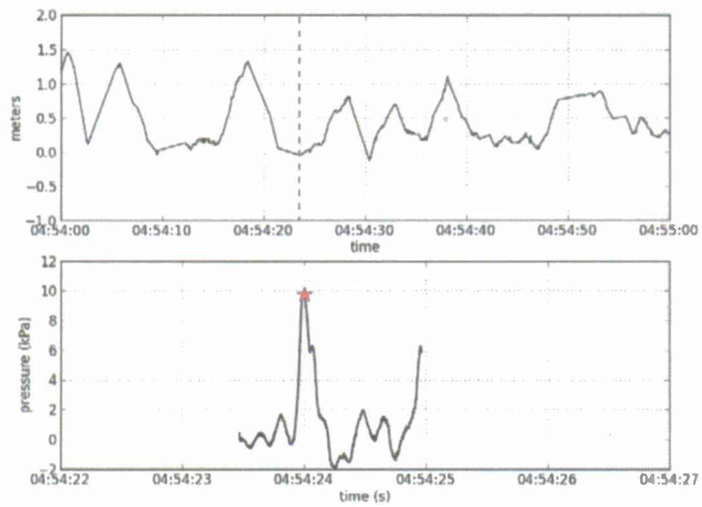

Figure 18. Laser altimeter (top) and pressure gage B1 (bottom) time series for 7 January 2012 (same series as Figure 14). Dashed line in top panel indicates location of impact indicated by red star in the bottom panel.

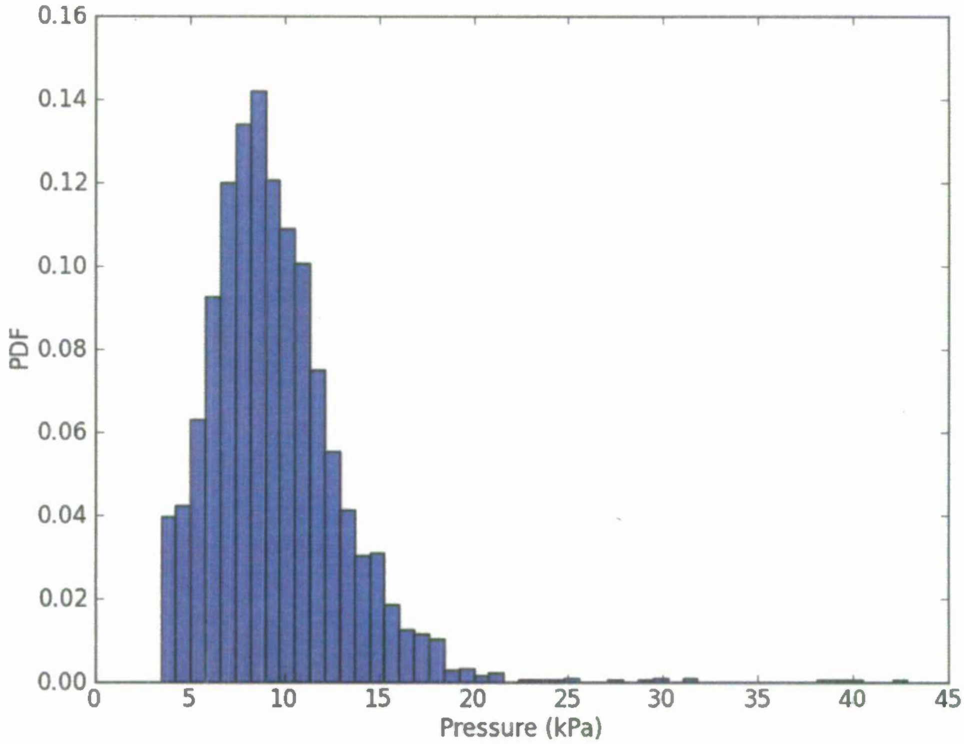

Figure 19. PDF of peak pressures measured on 7 January 2012 on pressure gage B1.

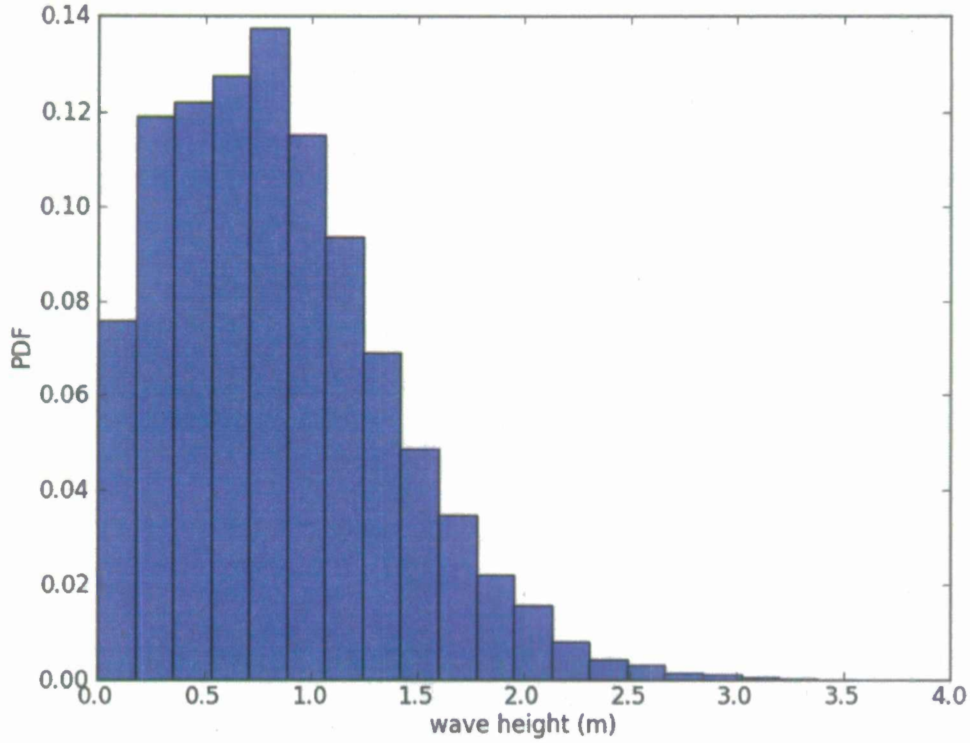

Figure 20. PDF of peak pressures measured on 7 January 2012.

SUMMARY

An instrumented plate has been designed and deployed at Scripps Pier for full scale wave impact measurements. A programmatic method for determining peak pressure values has been developed and was used to determine a probability density of slam values for 7 January 2012 on a single gage. Future work will include applying this method to additional data, and comparing the values with general sea state, as well as more specific wave characteristics.

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